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Shear Strength and Fracture Toughness of Steel Fibre Reinforced Concrete with Industrial Wastes

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Abstract: This Paper gives a review of research works performed on Steel Fibre reinforced concrete, the effects of copper slag, Ground Granulated Blast furnace Slag (GGBS) and Metakaolin on concrete when they are used to replace the cement and sand content in concrete. The project focuses on fracture toughness and shear strength properties of steel fibre reinforced concrete with industrial wastes. In this study, M30 grade concrete is used. The cement is replaced up to 20% with Metakaolin and Ground Granulated Blast furnace Slag (GGBS) in equal proportions. The river sand used as fine aggregate is replaced with copper slag up to 60%. The hooked end steel fiber addition is kept constant as 3% by weight of binder content. Specimens of size 250×50×50 mm are used with notch of constant width 3mm with different notch depth ratios of 0.1, 0.2, 0.3 and 0.4. The fracture toughness is determined by using three point and four point bending test. For shear strength L-shape specimens of size (150×150×150 mm – 150×90×60 mm) are used. The results are obtained and compared with the tesults of ordinary concrete mix.

I. INTRODUCTION

In India, concrete have been used extensively for the construction of houses, multi-storied buildings, roads, bridges and dams. But, the use of conventional concretes does not meet many functional requirements such as impermeability, resistance to frost and thermal cracking adequately. Avoiding cracks or controlling their widths is an important engineering problem. With the advancement of technology and increase in fields of application of concrete and mortar, the strength, workability, durability and other characters of the matrix need modifications to make it more suitable for any situation. Construction industry is one of the major users of the natural resources like sand, rocks, clays, minerals etc. The ever increasing unit costs of the usual ingredients of concrete have forced the construction engineer to think of ways and means of reducing the unit cost of its production. This can be overcome by replacing cement and sand with industrial wastes. This also leads to the solution of problems concerned with disposal of industrial wastes. During the last decades enormous development have been made in concrete technology. One of them is Fibre Reinforced Concrete (FRC) which is a composite material comprising of conventional concrete reinforced by the random dispersal of short, discontinuous, and discrete fibres of specific geometry. The principle motive behind incorporating fibers into a cement matrix is to increase the toughness and tensile strength and improve the cracking deformation characteristics of the resultant composite.

II. REVIEW OF LITERATURE

Many research projects on concrete and cementitious materials are being carried out throughout the world in order to improve their mechanical properties. The cementitious materials are typically characterized as brittle materials with low tensile strength and low shear capacity. However it has been studied that with the use of fiber reinforcement, the brittleness can be reduced thus resulting with improved strength, ductility and durability. Fracture properties are affects the safety of concrete structures. It is well known that the presence of cracks in structure decreases the strength of the structure. The improved pore structure of concrete by applying chemical, mineral admixtures and fiber materials causes densification of paste-aggregate transition zone, which in turn effects the fracture properties. Hence, it is necessary to investigate the effect of fracture properties of steel fiber reinforced concrete containing industrial wastes.

Copper slag and Blast furnace slag are the industrial by products which can be used with concrete in order to improve some the properties of concrete. The use of these products also solve the problems of their disposal. Brindha D & Nagan S (2010) carried out studies on utilization of copper slag as a partial replacement of fine aggregate in concrete. The density of concrete was increased by 6-7%. This was probably due to the higher specific gravity of copper slag. There was significant increase in the compressive strength of concrete due to the addition of slag in suitable proportions up to an optimum percentage by weight of sand. The compressive strength increased to a maximum of 35% with 40% replacement of sand by slag.

Chavan & Kulkarni (2013) carried out experimental studies on strength properties of copper slag as partial replacement of fine aggregate and concluded that the maximum strength was attained by replacing fine aggregate upto 40% by copper slag. Alnuaimi (2012) carried out studies on use of copper slag as a replacement for fine aggregate in RC slender columns. The percentage of copper slag as a replacement for fine aggregate varied from 0 to 100%. The increase in copper slag also led to higher slump and the mixture reached collapse in the 80 and 100% levels of copper slag. This is because of glassy surface of copper slag that absorbs less water than sand. Brindha et al., (2010) carried out experiments to assess the corrosion and durability characteristics of copper slag admixed concrete and reported that copper slag concrete exhibits good durability characteristics and can be used as an alternative to fine aggregate.

Suchita Hirde & Pravin Gorse (2015) investigated the effects of mechanical properties of M50 grade Fiber Reinforced Concrete with 0%, 10%, 20%, 30% & 40% replacement of cement by GGBS. The percentage of steel fiber was kept constant as 1.5%.The Load-Deflection behavior indicated increase in flexural stiffness and toughness up to 20% replacement of cement with GGBS. Awasare et al., (2014) analyzed the strength characteristics of M20 grade concrete with replacement of cement by GGBS with 20%, 30%, 40% and 50% and compared with plain cement concrete. The maximum compressive strength was achieved at 30% of GGBS replacement and tensile strength also gave good performance for 20%, 30% and 40% replacement which was more than normal plain concrete. Arivalagan (2014) evaluated the strength efficiency factors of hardened concrete, by partially replacing cement by various percentages of ground granulated blast furnace slag for M35 grade of concrete. He concluded that, since the grain size of GGBS is less than that of ordinary Portland cement, its strength at early ages is low, but it continues to gain strength over a long period.

Kaolintic clay heated at a temperature between 600°C to 800°C leads to dehydroxylation of the crystalline structure of kaolinite and forms metakaolin which possess pozzolanic properties. When Metakaolin is blended with Portland cement it improves the durability of concrete and mortar. Metakaolin removes chemically reactive calcium hydroxide from the hardened cement paste and also reduces the porosity of hardened concrete. Vinayak Vijapur et al., (2014) investigated the behavior of steel fibre reinforced polymer concrete with metakaolin replacement. He reported that the steel fibre reinforced polymer concrete with 30% replacement of cement by metakaolin shows higher workability , lower water absorption and lower sorpitivity as compared to 40% replacement of cement by metakaolin. Vikas Srivastava (2012) observed that the slump of concrete decreases with increase in metakaolin content. Yogesh et al., (2015) studied the effects of steel fibers and metakaolin on mechanical properties of concrete. They reported that the density of steel fiber reinforced concrete using metakaolin increased marginally over normal concrete due to metakaolin, which densifies the concrete because of its micro-filler effect due to the relatively finer particle size. Also the failure of beams occurred in the flexural zone. The width of crack is less in steel fiber reinforced concrete using metakaolin than plain concrete. Shelorkar (2013) investigated steel fibre reinforced concrete using Metakaolin. He observed that the concrete blocks incorporated with steel fiber increased its compressive strength by 8.91% and tensile strength by 26.94%. Metakaolin and steel fiber blocks exhibited an increase in flexural strength of concrete in 58.28%.

The shear strength of concrete is the resistance of one layer with respect to other during slip at common surface of contact (Maroliya 2012). Adding fibers to concrete makes it a homogenous and isotropic material and converts its brittle characteristics to ductile one. In term of structure performance, the inclusion of discrete fibers into the concrete matrix can arrest cracks and thereby control crack propagation. Not much work on shear strength of concrete has been reported by researchers. But fibre reinforced concrete possesses significant improvement in shear strength (Baruah and Talukdar 2007). JSCE (Japan Society of Civil Engineering) method of shear testing gives the average shear strength of CFRM (Continuous Fiber Reinforcing Material) materials by shear cutting. As this is not the simple method of testing, Bairagi & Modhera (2001) proposed a simpler method to determine the shear strength of fibre reinforced concrete specimens using compressive testing machine. They checked the feasibility and reliability of the test method proposed by them with the test method suggested by JSCE method. Results obtained by their proposed method were 10% higher than that of JSCE method. This method was adopted by several researchers including Manjunatha et al., Pamnani Nanak et al., Maroilya etc.

Manjunatha et al., (2014) investigated various mechanical properties of geopolymer concrete synthesized by activating Class F fly ash and ground granulated blast furnace slag with alkaline solution including shear strength. They concluded that the shear strength of geopolymer concrete increases with increase in GGBSS content and a corresponding decrease in fly ash content. Maroliya (2012) studied the influence of steel fiber variation on shear strength of RPC (Reactive Powder Concrete) by adding 1%, 2% and 3% fibres. He concluded that with addition of fiber the specimens do not fail suddenly and had significant influence on the rate of crack propagation and on the failure load. Also the results showed that higher the thickness of shearing plane higher the value of shearing strength and the optimum results can be obtained at 60 to 75 mm depth.

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The amount of fibers added to the concrete mix is expressed as a percentage of total volume of the composite and the value typically ranges from 0.1 to 3%. The fibre is described by a convenient parameter called aspect ratio. The aspect ratio of the fiber is the ratio of its length to its diameter. Fibers with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio. If the modulus of elasticity of the fiber is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material (Amit Rana 2013). Thirumurugan A & Sivaraja M (2015) investigated the shear, impact and fracture strengths of high-strength concrete reinforced with two different industrial waste fibres namely steel lathe waste and nylon waste fibres at different volume fractions (0.5%, 1.0%, 1.5% and 2.0%). They reported that the steel lathe waste fibres mainly contributed to limiting the crack initiation and lightweight non-metallic nylon fibres restricted the crack propagation. The combined advantages of these fibres provide high mechanical and fracture strength.

Banthia et al., (2009) studied the toughness enhancement in steel fibre reinforced concrete through fibre hybridization. The larger diameter crimped fibres were used with smaller diameter crimped fibres to maintain the workability and fibre dispersability. The results showed that hybridization significantly improved the toughness. It was also reported that all mixes were workable and proper fibre dispersion was achieved. Ahmed et al. (2007), have studied the strain hardening and multiple cracking behaviour of hybrid fibre reinforced cement composites containing different hybrid combinations of steel and polyethylene (PE) fibres under four point loading. The total volume fraction of fibres was kept constant at 2.5 percent to maintain a workable mix. Hybrid Steel – PE fibre composites showed lower ultimate strength but higher deflection capacity at the peak load than that of other fibre composites.

Priti A Patel et al., (2012) reported that the presence of fibres in concrete alerts the failure mode of material. It was found that the failure mode of plain concrete is mainly due to spalling, while the failure mode of fibre concrete is bulging in transverse directions. Sahin & Koksal (2011) investigated the effects of steel fiber strength (tensile strengths of 1100 and 2000 MPa) on mechanical and fracture properties of high strength concretes. They reported that significant influence of fiber with aspect ratios of 80 and 85 were observed on fracture energy characteristics. Deepa Raj et al., (2013) studied the fracture properties of steel fibre reinforced geopolymer concrete (GPC). They concluded that GPC exhibited 10-40% more fracture toughness than plain cement concrete. Also an increase in fibre content increased the fracture toughness. Palani et al., (2009) presented a review of on fracture analysis of concrete structural components. Studies had been conducted on crack growth analysis and remaining life prediction using linear elastic fracture mechanics (LEFM) principles. From the studies, significant difference between predicted and experimental observations was observed.

Prebhakumari K S & Jayakumar (2013) carried out studies on the fracture behavior of steel fiber reinforced high strength concrete (HSC) with particular emphasis on the size effect method. Three-point bending test was performed to determine the fracture parameters. They concluded that for an increase of crack size from 1/6th to 1/3rd of the depth of the specimen, the nominal bending stress at failure reduced by 72% for HSC. Jyoti Narwal et al., (2013) investigated the behaviour of steel fibrous reinforced concrete beams with conventional longitudinal reinforcement and shear reinforcement and reported that the fibrous concrete specimens exhibited better rotation capacity at ultimate load as compared to non-fibrous concrete specimens. Chen-Hui et al., (2013) reported that to some extent, the effective crack length represents the actual length of the crack in the calculating of the fracture parameters. The larger the depth of the precutting cracks, the larger the effective crack length.

III. CONCLUSION

Based on the literature review, it is proposed to replace the cement content of concrete with Metakaolin and GGBS upto 20%. The percentage replacement of river sand by copper slag are 20%, 40% and 60%. Since hooked end steel fibres have improved resistance to pull out from a cement-based matrix, they are used. The steel fibres addition is kept constant as 3%. The addition of steel fibres makes the concrete less workable, hence super plasticizer is used. The 7 mixes of concrete including control mix (mix with no replacement) are proposed with different percentages of metakaolin, GGBS and copper slag. Specimens of size 250×50×50 mm are used with notch of constant width 3mm with different notch depth ratios of 0.1, 0.2, 0.3 and 0.4. The fracture toughness is determined by using three point and four point bending test. For shear strength L-shape specimens of size (150×150×150 mm – 150×90×60 mm) are used. The test set-up suggested by Bairagi and Modhera is used to find the shear strength. The results are obtained and compared with the results of ordinary concrete mix.

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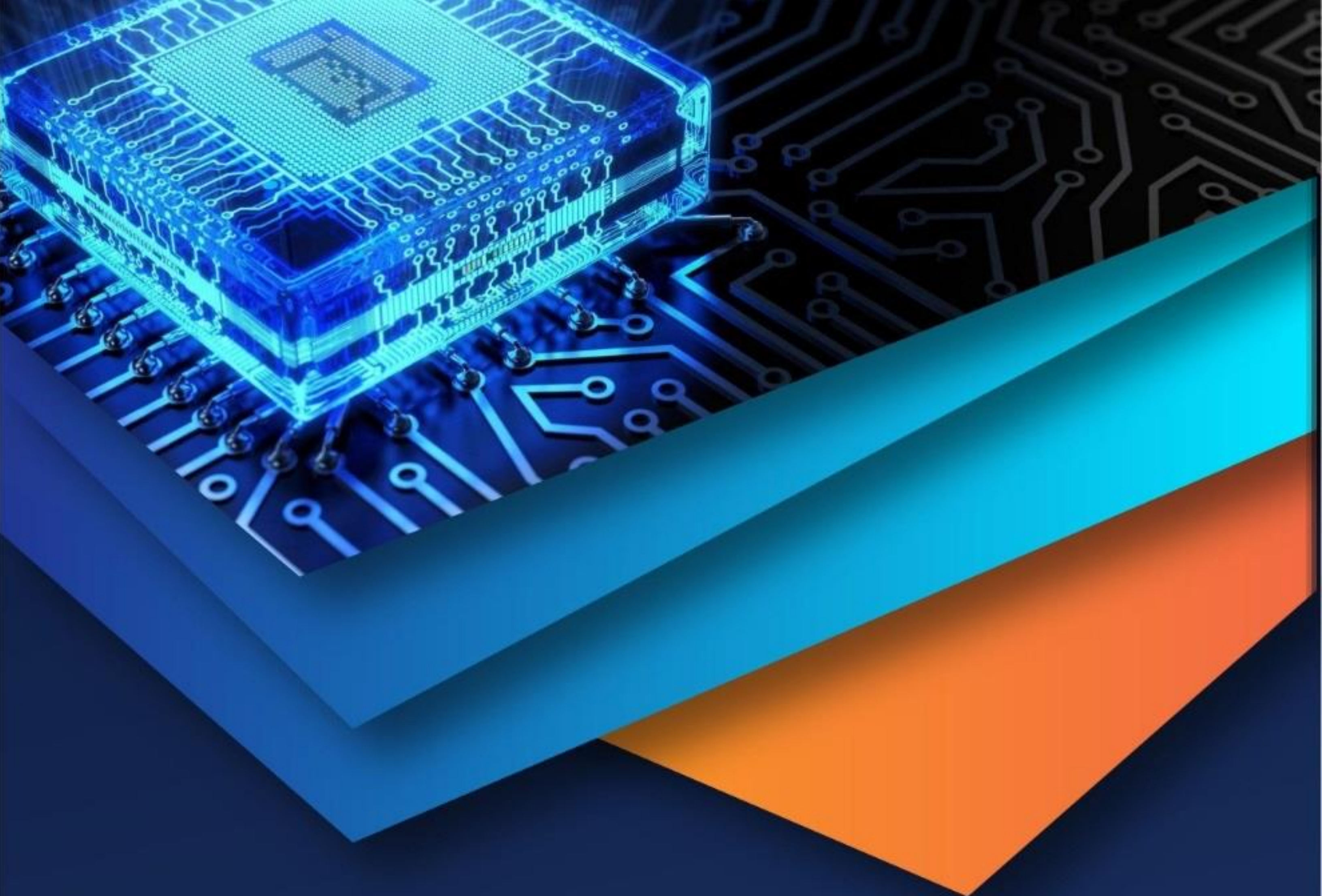

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